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At arm's length: competing and complementary mechanisms

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Abstract

Three experiments utilised video stimuli, showing an agent presenting objects in a behavioural stimulus-response compatibility paradigm, implicitly measuring responses to the agent's wrist orientation and hand of presentation. A vertical wrist orientation might cue a complementary action response in an ecological setting, thus testing spatial congruence against interactive and imitative responses. In experiment 1, there was a significant main effect of the actor's arm, ($p < .001$), responses to the actor's right arm being faster than to the left arm. There were two significant interactions in experiments 2 and 3, between the actor's arm and the participants' hand of response, ($p < .001$ and $p = .05$, respectively). Contrary to experiment 1, these interactions are akin to a spatial Simon effect. Possible interpretations of these results are discussed in terms of visual occlusion, kinematics, and affordances, all of which are aspects of spatial negotiation.

Introduction

Complementary actions are a prevalent phenomenon when defined in terms of dynamic spatial negotiation. As one moves around the environment, one must negotiate obstacles in one's path, and complementary actions necessarily arise when one person's movement impacts upon another, i.e. we act and react to the actions of others, for example by allowing another to pass in a narrow corridor by moving aside, as discussed by Wundt (1912) in his consideration of the human agent in terms of social environment.

Similarly, Helbing and colleagues (see, for example, Helbing, 2001, & Helbing & Molnar, 1995) utilise computer modelling to predict group behaviour of spatial negotiation. It transpires that particular behavioural patterns naturally evolve, for example when cars became more common some time after their invention, driving behaviours evolved, before being formalised into various laws such as the UK's Highway Code (Directgov, Retrieved September 25, 2011) and the European guidelines agreed during the 1968 Vienna Convention (United Nations, 1968).

Examination of such group behaviours seems to indicate governance by smaller social groupings, in that the movement of one person impacts upon another, other such incidents being instigated in a combinatorial manner to create group behaviours in a kind of perpetual Brownian motion (Brown, 1866), as discussed in Ball's (2004) analogy with particle behaviour. The smallest unit of such complementary actions is dyadic, described by Knoblich and Sebanz (2008) as a "social coupling" (p.2022). Social couplings, as the term suggests, involve two people in a social scenario, i.e. undertaking joint actions.

Knoblich and Sebanz (2008) also discuss social couplings in terms of object transferral, which is the scenario of interest here. In object transferral, the agent receiving the object must consider both the giver's posture and the object itself.

Bodily posture in terms of grip type, wrist orientation and arm position depends upon the object in question. Gibson (1979) proposed that objects afford action possibilities, such that upon viewing a table, for example, one automatically evaluates the action possibilities such as sitting at or on the table. There is neuronal evidence which supports this contention (Murata, Fadiga, Fogassi, Gallese, Raos, & Rizzolatti, 1997); canonical neurones are those which respond both to viewing an object and grasping an object (Murata, et al., 1997). Some canonical neurones were found to preferentially respond to particular grip types, others still to three dimensional visual stimuli (Murata, et al., 1997).

Canonical neurones might be described as a motor-environment coupling, such that on sight of an apple, for example, one might automatically and unconsciously prepare oneself to grasp the apple using a wide "power grip" (Ellis & Tucker, 2000, p. 453). The power grip uses the fingers to oppose the thumb, allowing efficient object grasping. These functional linkages have been termed "micro-affordances" (Ellis & Tucker, 2000, p. 453), relating as they do to Gibson's (1979) theory of affordances, i.e. the holistic action possibilities which objects in our environment invite, but in a more specific sense, relating to aspects of objects, such as handles, and the differing appropriate grip types to which they relate (Ellis & Tucker, 2000). For example a calculator can be grasped at either side to be lifted or utilised by one-fingered button-

pressing (Jax & Buxbaum, 2010), or a guitar, which can be lifted by the strap or neck.

The stimuli used in the current experiments were palm-sized objects and largely symmetrical, in order that objects had only one affordance, constrained by the agent's hand in the vertical wrist orientation, priming an implicit, anatomically congruent grasp, with implicit grasping with either hand possible in the horizontal wrist condition. Object affordances were therefore held constant in order to measure responses to the agent's grip.

If we do automatically process affordances on sight of an object, we may be able to base our decision on the properties of the object and its environs (for example, Corney, Haynes, Rees and Lotto (2009) demonstrate how background context changes colour perception). Research undertaken by Ellis and colleagues (cf Symes, Ellis, & Tucker, 2005; Tucker & Ellis, 1998; Vainio, Ellis, & Tucker, 2007) appears to demonstrate object property effects; congruence between an object's handle orientation and the hand of response facilitates responding. Micro-affordant evidence was implicit, explicit tasks being used to mask the effects under investigation, for example participants categorising objects associated with kitchens or garages (Symes, et al., 2005), or judged as upside-down or upright (Tucker & Ellis, 1998), the implicit measure being the handle orientation of the object.

It is necessary for micro-affordances to be incorporated into a behavioural sequence; i.e. the grasping hand is attached to a reaching arm. Jeannerod (1984, as cited in Jacob & Jeannerod, 2003) found hand prehension is not made until 60%-70% through the act of reaching (measuring from the moment the hand and/or arm begins to move to the time when the object is secured). Coupled with this, neurones in F1 which respond to finger positioning are not directly connected to visual areas (Rizzolatti & Sinigaglia, 2006). If this is the case, it may be that an appropriate grip type template is chosen, the hands being able to form a number of templates, such as a two- or five-jaw chuck (Pinker, 1997), and indeed some canonical neurones do respond to specific grip types (Murata, et al., 1997). However, the question remains exactly where in the decision process this responding occurs – before, during or after the hand moves, or any, or all three? On approaching the object, finer tuning may be made by visual and tactile motor assessment, grasp posture necessarily being slightly larger than the target object before the fingers close around it (Jeannerod, 1984, as cited in Jacob & Jeannerod, 2003). Before this, a decision at some point must be made as to which hand grasps an object. All else being equal we may choose our dominant hand. However, in complex cases, if micro-affordances dictate suitable wrist orientations and grip types, this may greatly influence the hand selection process, later grasp formation allowing for correction and precise finger placement during flight and upon the grasp itself. This also allows for some correction should the target object move. Indeed, participants in Bridgeman, Lewis, Heit and Nagle's (1979) experiment unconsciously adjusted their grasp to successfully grasp objects which moved during a saccade. This allows efficient coping with the dynamic environment in which we live.

Rizzolatti and Sinigaglia (2006) propose a neural circuit for micro-affordance processing and decision-making in grasping, suggesting that the anterior intraparietal area ("AIA"), based on object meaning provided by the inferotemporal

cortex ("ITC") and visual information provided by posterior parietal areas, interacts with area F5 in selecting an appropriate motor act. Rizzolatti and Sinigaglia (2006) therefore suggest that affordances are calculated by the AIA and are then translated to appropriate motor acts by area F5, which are communicated back to the AIA. Evidence from Ellis and Tucker (2000) suggests a potential problem with this explanation of events, because their findings of micro-affordance behaviours are irrelevant to the task at hand, implicating a non-conscious element which is perhaps not adequately explained by Rizzolatti and Sinigaglia's (2006) model. Much depends on the interpretation of the meaning aspect of the sequence, supposedly provided by the ITC; Ellis and Tucker's (2000) findings seem to suggest micro-affordance processing without the conscious intention (or indeed opportunity) to act upon objects, both due to the explicit task, and by a glass screen preventing actual grasping of the objects. This may suggest that automatic processing does not fully inhibit alternative responses before the final response is made, or that ecological responses (such as implicit grasping as in this case) are not entirely inhibited by abstract tasks such as a button-press response to an object categorisation task.

As well as the choice of arm and grip type, wrist orientation is another aspect of the grasping motor sequence. Parsons (1994) found participants' reaction times were facilitated by viewing realistic and comfortable wrist orientations rather than unrealistic or uncomfortable wrist orientations. However, Park (1998) found cultural differences in gift-giving postural behaviours with regard to wrist orientation, suggesting a social aspect of object transferral. In object transferral, an overhand grip may be inappropriate if the giver wishes to present the object to the receiver, because the hand will occlude the object. Therefore, for secure grasping of objects palm-sized or larger, the most comfortable wrist rotation in the shoulder would be vertical, creating least tension in the rotator cuff (Gray, 1977).

Thus, it seems mechanisms process the micro-affordances of objects and the giver's posture. The other component of object transferral is the receiver's reconciliation of these mechanisms. Microscopic complementary actions (Newman-Norland, van Schie, van Zuijlen, & Bekkering, 2007) are manifest by actions which, as the name suggests, complement one another, such as hand-shaking, in which one person's hand is dovetailed with another's hand in anatomical rather than spatial congruence. Newman-Norland, et al. (2007) found larger BOLD signals to such microscopic complementary actions using fMRI methodology. Similarly, Iacoboni et al. (2001) and Koski et al. (2002) found greater activation for anatomically congruent tasks rather than spatially congruent tasks. Further, Flach, Press, Badets and Heyes (2010) found faster behavioural responses to an agent's hand in a forward-moving response, rather than either a backward-moving response or to abstract target objects, in a hand-shaking paradigm. Complementary action responses are uncommon in the literature (cf Cappella, 1997; Iacoboni, et al., 1999; Iacoboni, et al., 2001; Koski, et al., 2002), much research reporting Spatial Simon ("SS") effects (Simon, 1969). A further alternative finding is Michaels' (1988) Dynamic Spatial Simon ("DSS") phenomenon, occurring when animated square stimuli moved across the screen, participants responding to the end destination, rather than starting position. If it is the case that the Simon effect (1969) is an abstract task manifested by ecological behaviours (such that we ordinarily respond to objects nearer to our hand), as suggested by Ellis (2007), a DSS effect may be much the same as a complementary action, differing in its specificity only that DSS does not involve grip

congruence. However, Clark (1997) suggests that mechanisms complement one another in a cumulative fashion, Csibra (2007) arguing further that we process the actions of another in order to react. Therefore early response times may reflect an SS manifestation while later response times may reflect a different mechanism, as the vision and action systems process visual input and calculate appropriate reactions. Thus, comparison between SS and DSS effects with complementary action and imitative manifestations may be valid due to the seeming anthropomorphism attributed to abstract moving objects (Heider & Simmel, 1944) and robots (Oberman, McCleery, Ramachandran, & Pineda, 2007), arguably because the most common dynamic objects we encounter are sentient.

Ordinarily, in social interaction experiments, responses are spatially congruent with the target, so that, for example, a target to the left-hand side of the screen results in a left-handed response (cf Cappella, 1997; Iacoboni, et al., 1999; Iacoboni, et al., 2001; Koski, et al., 2002). Spatially congruent results may be attributed to SS effects or to mirror neurones. Mirror neurones have been described as neurones which respond both to one's own actions and the actions of others, if both oneself and another have the same end-goal in relation to an object (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996), such as button-pressing to switch on a light.

The whole-body posture of one's partner in social couplings is often imitated (cf Iacoboni, Woods, Brass, Bekkering, Mazziotta, & Rizzolatti, 1999; Iacoboni, et al., 2001; Koski, et al., 2002). Manifold reasons suggested for imitation include liking the other person (Bernieri & Rosenthal, 1991), and wishing liking to be reciprocated (Bavelas, Black, Lemery, & Mullett, 1986). Much behavioural research reports mimicry effects (see for example Cappella, 1997) and indeed Chartrand and Bargh (1999) define unconscious mimicry as a "chameleon effect" (p. 893).

Imitation may manifest as identical to SS responses. Differing wrist orientations may differentiate SS and DSS effects from imitative and complementary actions, respectively, the horizontal wrist orientation affording a grasp from either hand, testing spatial effects, the vertical hinting at the more complex processes.

Complementary actions, which in the current experiments oppose imitative manifestations, have been found in behavioural research, particularly after entrainment, such as Flach, et al., (2010) and Knoblich and Sebanz (2008). In the case of whole-body complementary actions, effects are more prevalent; Tiedens and Fragale (2003) draw comparison between complementary dominant and submissive behaviours in other animals with similar bodily postures in humans.

Finally, our visual array is often cluttered, such that we might select and grasp one object from many. Two examples of this cluttered environment are reported in Symes, et al., (2005), and Ellis, et al., (2007), both using a similar behavioural paradigm to Ellis and Tucker (2000) in a situation in which distractor objects were presented with target objects. Results from Ellis, et al., (2007) suggest that distractor objects have an effect on grasping behaviour despite no intention to act upon them. Thus, distractor effects are another factor to consider in the current experiments, Experiment 1 presenting two possible target objects whereas Experiments 2 and 3 present only one.

Thus, the three experiments reported herein compare imitative and interactive responses by examining interactions between the agent's arm and wrist orientation, with a further examination of the attentional aspects of social interactions by use of distractor objects.

Experiment 1

Method

Participants

Twenty-two participants were recruited from the student participation pool at the University of Plymouth and awarded course credit. All participants were right-handed and naïve as to the purpose of the study. Two participants' data were excluded due to error rates greater than 90%.

Apparatus and materials

Video stimuli were created in a room brightly lit with fluorescent lighting, blackout blinds being lowered to prevent daylight changes and shadowing.

A Canon Legria HFM 36 video camera, supported by a Camlink TPPRE tripod, was used to create the stimuli. Stimuli comprised 80 videos, lasting 880 milliseconds. In responses slower than 880 milliseconds, the end frame was displayed until the trial timed out at 3,000 milliseconds.

Each video consisted of a human agent from the neck down, facing the camera and sat at a table. The agent moved an object from either the left or right rear of a table-top, towards the centre front of the table (see Figures 1 and 2 for example photographic still images of the opening and end frames, respectively).

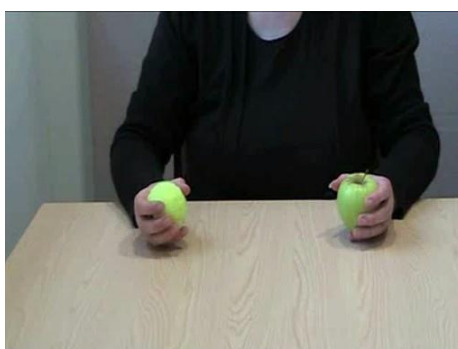


Figure 1: Example opening frame of video (vertical wrist orientation)

Objects were presented with the left or right hand, the empty hand resting out of sight on the agent's lap. The agent's wrist orientation varied between a vertical wrist position (shown in Figure 1) or a horizontal wrist position (shown in Figure 2). The conditional wrist orientation was maintained throughout the duration of videos.



Figure 2: Example end frame of video (right arm, horizontal wrist orientation)

The objects held in the videos consisted of 10 natural objects and 10 man-made objects. See Table 1 for a full list of the objects used.

Table 1: Paired objects

Manmade Objects	Natural Objects (All Real)
Tennis Ball	Apple
Plastic Box	Lemon
Light Bulb	Mushroom
Candle	Onion
Soft Drink Can	Mango
Alarm Clock	Sweetcorn Cob
Double Hole-punch	Pepper
3 Way Electric Plug Adaptor	Pear
Ceramic Pot	Potato
Tinned Tomatoes	Tomato

Procedure

Participants sat approximately 40cm away from a desktop computer screen and were asked to respond as quickly as possible and attempt to maintain 90% accuracy. Participants were presented with 20 practice trials, in which they were requested to categorise the object in each video as either natural or man-made. Responses were made with the index finger of either their left or right hand, on the extreme left or right buttons, respectively, of an E-Prime 5-button response box.

The practice session presented random trials from the stimulus set, requiring either a left-handed response to natural objects.

The practice session was followed by a block of 160 trials in which the 80 stimuli were each presented once, at random, before a randomised cycle began again. The hand mapping remained the same as the practice block. After an opportunity to take a rest, a second block of 160 trials began during which the hand mapping variations of the response buttons to object categorisation exchanged places, thus counterbalancing the hand mapping within participants. Each response was followed by a

1,500ms feedback screen, providing participants with the accuracy of the response and reaction time. However, responses less than 200ms were set to trigger a text box on-screen with the message “Your response was too fast. Please try again. Press return to continue.” Similarly, if no response was made a text box appeared with the message “No response detected. Please try again. Press return to continue.” Responses (or their lack) in these cases were recorded as inaccurate. Feedback was not provided in these cases, the experiment program progressing to the next screen in the process. A blank screen was then shown after each trial, regardless of response, for 500ms, to allow for after-images to fade before the experiment program moved on to the next trial.

Results

A mixed Analysis of Variance (“ANOVA”) performed on data trimmed to within two standard deviations tested the three experimental conditions, being agent’s arm, participants’ responses and agent’s wrist orientation, as well as the object categorisation and experiment blocks to test the hand mapping.

There was a significant main effect of the actor’s arm, $F(1,76)=26.13$, $p<.001$, responses to the actor’s right arm ($M=644.99$) being faster than to the left arm ($M=668.77$). There was also one significant four-way interaction, between the actor’s arm, wrist orientation, block presentation and participant response, $F(1,76)=5.11$, $p=.027$. A table of means can be found at Table 2.

Table 2: Block * Response * Arm * Wrist

Block	Participant Response	Actor’s Arm	Wrist Orientation	Mean
Block 1	Left	Left	Horizontal	670.65
			Vertical	681.30
		Right	Horizontal	640.55
			Vertical	650.65
	Right	Left	Horizontal	681.55
			Vertical	666.00
		Right	Horizontal	644.80
			Vertical	649.90
Block 2	Left	Left	Horizontal	675.10
			Vertical	666.75
		Right	Horizontal	656.55
			Vertical	668.50
	Right	Left	Horizontal	652.00
			Vertical	656.80
		Right	Horizontal	625.35
			Vertical	623.60

Error rates: An ANOVA performed on the error rates tested all main effects and all interactions between them. The main effect of wrist orientation was significant, $F(1,76) = 5.35$, $p=.02$, with responses to the horizontal wrist orientation being faster ($M = .68$ compared to $M = .87$ for the vertical wrist orientation). There were no other significant main effects or interactions.

Experiment 2

Method

It was felt that clarification of Experiment 1 was required, to investigate whether the results were due to an attentional process, in that participants had to attend to the moving object in order to complete the categorisation task. Therefore, only one object was presented. Further, a social aspect was investigated, video footage showing the actor's face rather than just the torso.

Participants

Forty participants were recruited from the student participation pool at the University of Plymouth and awarded course credit. All participants were right-handed and naïve as to the purpose of the study. Two participants' data were excluded due to error rates greater than 90%.

Apparatus and materials

Stimuli were largely identical to Experiment 1, with the exception that video stimuli lasted 1,600 milliseconds. Again, in responses slower than 1,600 milliseconds, the end frame was displayed until the trial timed out at 3,000 milliseconds.

Further, each video consisted of a human agent facing the camera and sat at a table. The agent held only one object, the empty hand resting out of sight on her lap. The agent moved the target object from the centre-rear of the table-top, towards the centre front of the table (see Figures 3 and 4 for example photographic still images of the opening and end frames, respectively). All other apparatus and materials were identical to Experiment 1, aside from changes to some objects as listed in Table 3.

Table 3: Unpaired objects

Manmade Objects	Natural Objects
Light Bulb	Real Potato
Plastic Box	Real Tomato
3 Way Electric Plug Adaptor	Plastic Avocado
Ceramic Pot	Polystyrene Lemon
Double Hole-punch	Plastic Orange
Tinned Tomatoes	Polystyrene Apple
Alarm Clock	Plastic Pear
Candle	Polystyrene Peach
Glass Jar	Plastic Onion
Soft Drink Can	Plastic Pepper



Figure 3: Example opening frame of video (left arm, horizontal wrist orientation)



Figure 4: Example end frame of video (right arm, vertical wrist orientation)

Procedure

Participants followed an identical procedure to Experiment 1, with the addition of counter-balancing of the hand mapping, so that half the participants responded with their left hand to natural objects, and their right to man-made, the other half of participants being allocated to the opposite hand mapping. Participants' hand mapping remained the same as the practice block for the duration of the first experimental block. After an opportunity to take a rest, a second block of 160 trials began during which the hand mapping variations of the response buttons to object categorisation exchanged places, thus counter-balancing the hand mapping within participants, the between-participant mapping allowing analysis of order effects.

Results

Data were trimmed to within two standard deviations before performing a mixed ANOVA to test the three experimental conditions as before.

No significant main effects were found, however there was a two-way interaction between the actor's arm and the participants' hand of response, $F(1,144)=41.23$, $p<.001$, as shown in Figure 5.

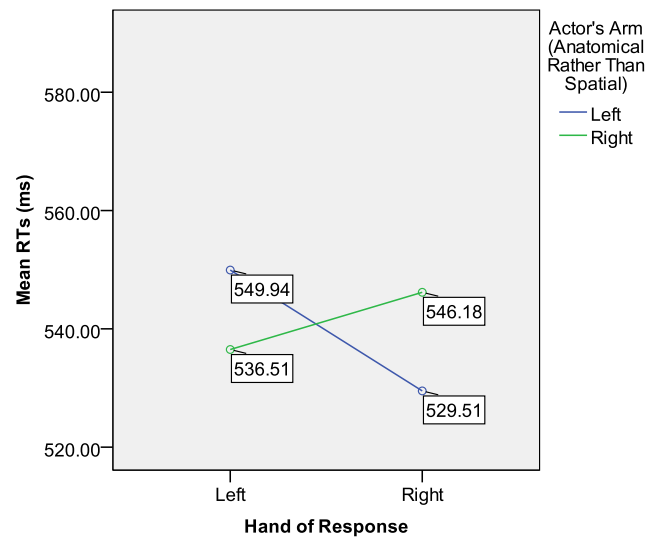


Figure 5: Actor Arm by Participant Hand of Response Interaction

There was also a significant five-way interaction, between actor's arm, wrist orientation, experiment block, object category and participant response, $F(1,144)=4.15$, $p=.04$. A table of means is provided at Table 4.

Table 4: Means of Block * Object Category * Hand of Response * Arm * Wrist

Block	Object Category	Participant's Response	Actor's Arm	Wrist	Mean
				Orientation	
Block 1	Manufactured	Left	Left	Horizontal	556.37
				Vertical	572.68
			Right	Horizontal	551.74
				Vertical	558.47
		Right	Left	Horizontal	529.74
				Vertical	527.63
			Right	Horizontal	541.37
				Vertical	543.95
	Organic	Left	Left	Horizontal	531.37
				Vertical	525.26
			Right	Horizontal	505.16
				Vertical	514.05
		Right	Left	Horizontal	499.84
				Vertical	518.90
			Right	Horizontal	530.26
				Vertical	533.42
Block 2	Manufactured	Left	Left	Horizontal	575.79
				Vertical	567.79
			Right	Horizontal	567.84
				Vertical	560.21
		Right	Left	Horizontal	544.16
				Vertical	

Organic	Left	Right	Vertical	546.74
			Horizontal	559.21
		Left	Vertical	561.26
			Horizontal	531.53
			Vertical	538.74
	Right	Right	Horizontal	514.05
			Vertical	520.53
		Left	Horizontal	534.16
			Vertical	534.90
			Right	Horizontal
		Vertical	563.11	

Error rates: An ANOVA performed on the error rates tested all main effects and all interactions between them. The main effect of experiment block was significant, $F(1,144)=13.79$, $p<.001$, with responses to block 1 being faster ($M = .65$ compared to $M = 1.06$ for block 2).

There were also two significant interactions, being agent arm by participant response, $F(1,144)=26.62$, $p<.001$, as shown in Figure 6. This response pattern was similar to mean response times, indicating a lack of a speed/accuracy trade-off. There was also a three-way interaction between wrist orientation, experiment block and participant response, $F(1,144)=4.61$, $p=.03$. A table of means is provided at Table 5.

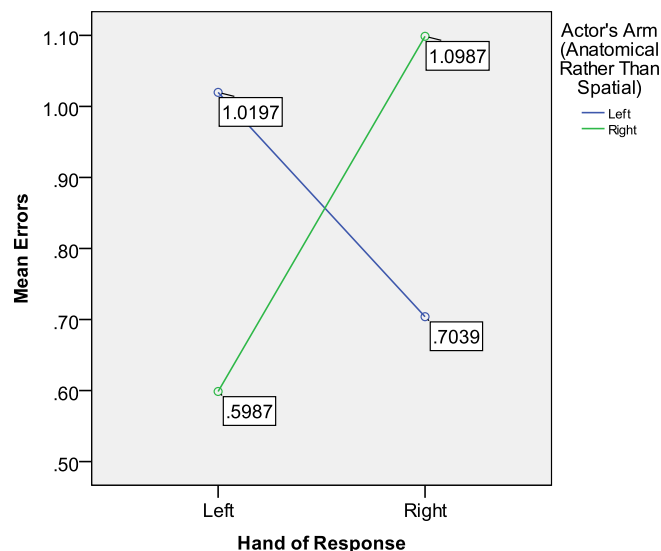


Figure 6: Actor Arm by Participant Hand of Response Interaction of Errors

Table 5: Means of Block * Hand of Response * Wrist

Block	Participant's Response	Wrist Orientation	Mean
Block 1	Left	Horizontal	.65
		Vertical	.65
	Right	Horizontal	.80
		Vertical	.51
Block 2	Left	Horizontal	1.00
		Vertical	.95
	Right	Horizontal	.96
		Vertical	1.33

Experiment 3

Method

The aim of Experiment 3 was to rule out any spatial effects between Experiments 1 and 2 by presenting only one object as in Experiment 2, and with the same camera angle as Experiment 1, with only the actor's torso in view. Further, an investigation was made of entrainment by presenting the wrist orientations in blocks, counter-balanced between participants.

Participants

Forty-two participants were recruited from the student participation pool at the University of Plymouth and awarded course credit. All participants were right-handed and naïve as to the purpose of the study. Two participants' data were excluded due to computer error, and error rates greater than 90%, respectively.

Apparatus and materials

Stimuli were largely identical to Experiment 1, with the exception that video stimuli lasted 1,000 milliseconds. For responses slower than 1,000 milliseconds, the end frame was displayed until the trial timed out at 3,000 milliseconds.

Further, each video consisted of a human agent, again from the neck down akin to Experiment 1, facing the camera and sat at a table. Similar to Experiment 2, the agent held only one object, the empty hand resting out of sight on her lap. The target object movement was the same as Experiment 1, the agent moving the target object from either the left or right rear of a table-top, towards the centre front of the table (see Figures 7 and 8 for example photographic still images of the opening and end frames, respectively). All other apparatus and materials were identical to Experiment 1, aside from changes to some objects as listed in Table 6.



Figure 7: Example opening frame of video (right arm, vertical wrist orientation)



Figure 8: Example end frame of video (left arm, horizontal wrist orientation)

Table 6: Unpaired objects

Manmade Objects	Natural Objects
Light Bulb	Real Potato
Plastic Box	Real Nectarine
3 Way Electric Plug Adaptor	Plastic Avocado
Ceramic Pot	Polystyrene Lemon
Double Hole-punch	Plastic Orange
Tinned Tomatoes	Polystyrene Apple
Tennis Ball	Plastic Pear
Alarm Clock	Polystyrene Peach
Candle	Plastic Onion
Glass Jar	Plastic Pepper

Procedure

Participants followed an identical procedure to Experiment 2, with an additional blocked factor of wrist orientation. Half of the participants were presented with the practice session and first experimental block where the agent held a horizontal wrist orientation, the other half of participants being presented with the agent having a vertical wrist orientation. There were thus four separate conditions, one quarter of participants responding to the natural objects with their right hand and the agent’s hand in a vertical wrist orientation, another quarter responding to natural objects with their left hand and the agent’s hand in a vertical wrist orientation, and so on.

Results

A mixed ANOVA performed on data trimmed to within two standard deviations as before revealed no significant main effects, although there were three two-way interactions and two three-way interactions. There were significant two-way interactions, the first being agent arm by participant response, $F(1,144) = 34.06$, $p=.05$, right-handed responses being faster to the left arm ($M=542.81$) than the right ($M=552.86$), and left-handed responses being faster to the right arm ($M=547.66$) than to the left ($M=562.13$). Secondly, the interaction between agent arm by object category was also significant, $F(1,144) = 3.92$, $p<.001$, responses to organic objects being faster to the left arm ($M=542.09$) than the right ($M=544.03$), and responses to manufactured objects being faster to the right arm ($M=556.49$) than to the left ($M=562.85$). The interaction between blocks by wrist orientation was also significant, $F(1,144) = 5.29$, $p=.02$, as shown at Figure 9.

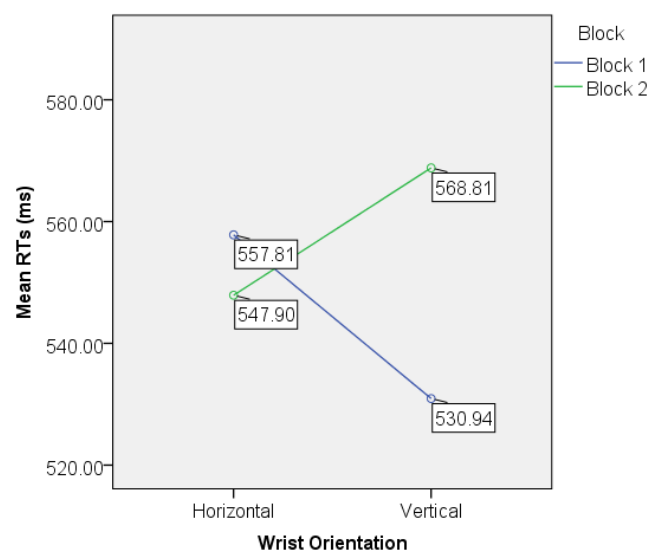


Figure 9: Block by Wrist Orientation Interaction

A significant three-way interaction was found between agent arm by block by participant response, $F(1,144) = 10.01$, $p=.002$. The response pattern of block 1, shown at Figure 10, reflected the response pattern of the overall interaction between agent arm and participant response reported above. The graph showing the change in response pattern in block 2 is shown at Figure 11.

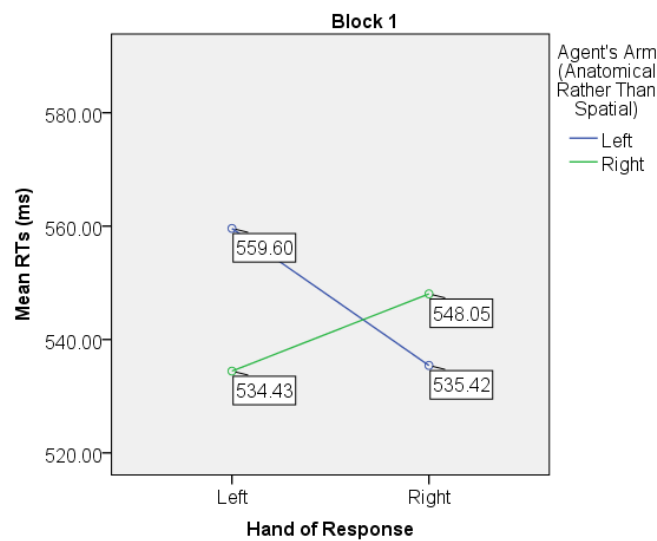


Figure 10: Block 1 Interaction of Participant Response by Agent's Arm

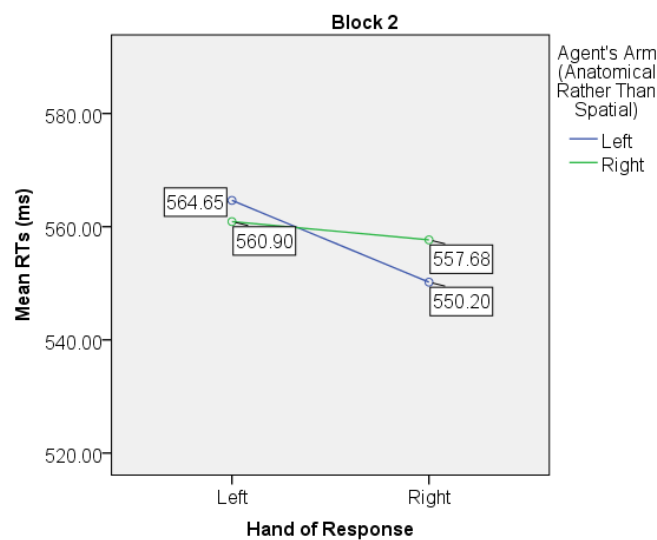


Figure 11: Block 2 Interaction of Participant Response by Agent's Arm

An ANOVA of the raw data tested all effects detailed above. Of interest, a main effect of agent arm was significant ($F(1,144)=7.57$, $p<.01$), participants responding faster to the agent's right arm ($M=563.15$), compared to the left ($M=570.50$). A significant two-way interaction ($F(1,144)=16.71$, $p<.001$) showed faster right-handed responses to the agent's left arm ($M=562.19$) rather than the right ($M=565.76$), left-handed responses being faster to the right arm ($M=560.54$) compared to the left ($M=578.8$).

Response patterns to a three-way interaction of agent arm by block by participant response were similar in kind to the trimmed data but with larger differences in block 1 and smaller differences in block 2, $F(1,144)=7.76$, $p<.01$.

The second significant three-way interaction of block by object category by

participant response, $F(1,144)=10.40$, $p=.002$, manifested by a mirror-image crossover of faster responses to organic objects with participants' left hand in block 1, changing to the right hand in block 2, the slowest responses being to manufactured objects by participants' left hand in block 1, and right hand in block 2, as set out in Figure 12.

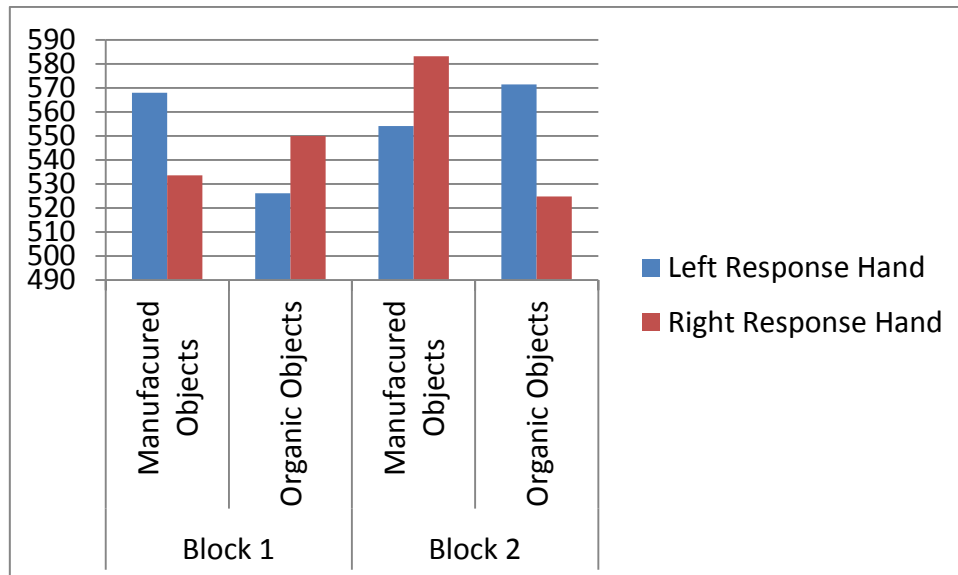


Figure 12: Mean response times (ms) showing interaction between block, object category and response hand

Error rates

An ANOVA performed on the error rates tested all main effects and all interactions between them. The main effect of Object Category was significant, $F(1,144) = 9.96$, $p<.01$, with responses to organic objects being faster ($M = 1.51$ compared to $M = 2.24$ for manufactured objects).

There were also two significant interactions, being agent arm by participant response, $F(1,144) = 4.63$, $p=.03$, the error numbers being greater for right-handed responses to the right arm ($M=2.15$) as opposed to the left arm ($M=1.81$), error numbers in left-handed responses to the right arm ($M=1.59$) being fewer than to the left ($M=1.96$). This response pattern was similar to mean response times, indicating a lack of a speed/accuracy trade-off. There was also a three-way interaction between agent arm by participant response by block, $F(1,144) = 13.96$, $p<.001$, again indicating no speed/accuracy trade-off in block 1, as shown in Figure 13, Figure 14 showing a speed/accuracy trade-off in Block 2.

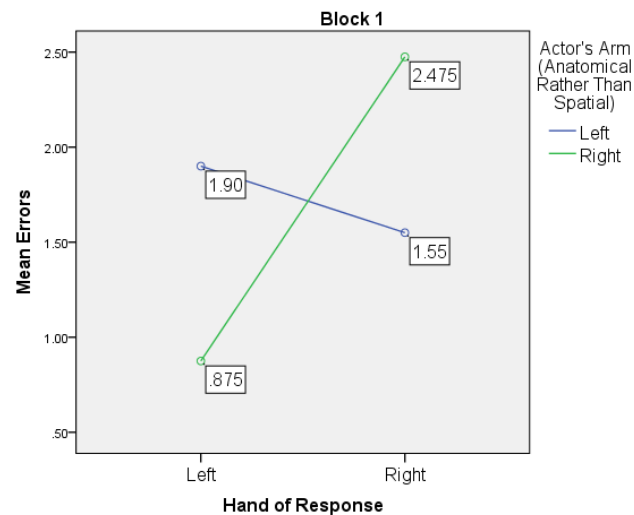


Figure 13: Block 1 Errors Interaction of Participant Response by Agent's Arm

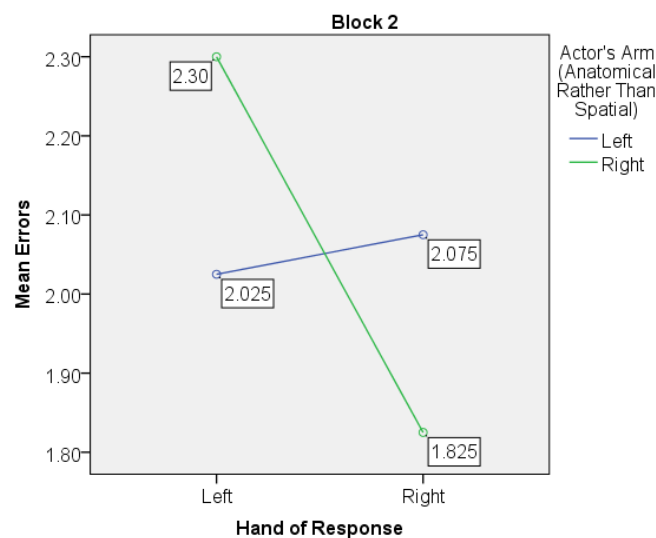


Figure 14: Block 2 Errors Interaction of Participant Response by Agent's Arm

General Discussion

Within-subjects analysis of the trimmed data of Experiment 1 indicated faster participant responses to the agent's right arm, which always began to the left-back of the screen, moving to centre-front.

The results of Experiment 2 indicated a spatial Simon Effect in the two-way interaction between the agent's arm and the participant's hand of response.

In Experiment 3, within-subjects analysis of the raw data echoed the behavioural pattern of Experiment 1, participant responses again being faster to the agent's right arm. Further, a significant interaction of agent arm by participant response showed right-handed responses were largely the same to either of the agent's arms, whereas left-handed responses were faster to the actor's right arm. Right-handed responses

found here are somewhat unusual in view of previous findings (cf Cappella, 1997; Iacoboni, et al., 1999; Iacoboni, et al., 2001; Koski, et al., 2002) of SS effects. However, the current Experiment 1 found similar differences in handedness, albeit differences were more marked than those of the current study, such that there was no interaction between the agent's arm and participant responses, due to responses being faster to the agent's right arm regardless of participants' response hand.

For Experiment 3, however, these effects largely disappeared on trimming the data to two standard deviations; the significant interaction manifesting an SS response pattern, as shown in Figure 9 above.

Analysis of Experiment 3 also revealed significant interactions between agent arm and object category, and a three way interaction of participant response, object category and block. Reasons for these results are unclear, however it is interesting to note that responses to both the agent's left arm and participants' left hand were faster to organic objects, the pattern changing for the latter in block 2. This may suggest a preference for our own and others' left hand to organic objects except in block 2.

The inference of imitative or complementary action mechanisms cannot be made in Experiment 2, because there was no interaction between wrist orientation and congruent participant responses to the agent's arm. Faster responses to a vertical wrist orientation when the agent's arm was distal to the hand of response may have implied complementary action facilitation because the wrist orientation in that scenario does not afford spatially congruent object transferral. Responses in Experiment 1 to the right-hand of the agent, however, may be indicative of interaction if participants anticipate most people would be right-handed. However this is not necessarily an interactive response, but rather an expectation effect.

Neither Experiment 1 nor 2 found any effect of the wrist orientation, presentation of which was randomised. Therefore the blocked wrist orientation factor in Experiment 3 may be comparable to experiments utilising entrainment such as Flach, et al., (2010) and Knoblich and Sebanz (2008), the difference here being the implicit and visual nature of entrainment rather than explicit motor entrainment in Griffiths and Tipper (2009) and Knoblich and Sebanz (2008). However, there was a significant interaction between wrist orientation and block in Experiment 3. A large difference was occasioned by the vertical wrist orientation, being faster during block 1. Motor entrainment has shown that it is possible to achieve complementary action responses in social couplings (cf Flach, et al., 2010; Knoblich & Sebanz, 2008), rather than the more common SS responses (Iacoboni, et al., 1999; Iacoboni, et al., 2001; Koski, et al., 2002; Cappella, 1997). The current experiments utilised visual entrainment – i.e. watching another perform an action - by use of the blocked wrist orientation. This appears to have had some effect on response patterns, over and above the change in hand mapping, due to the faster initial responses to the vertical wrist orientation. Aside from hand mapping changes, more abstract task difficulty could be explored, such as a secondary categorisation task or remembering an answer to an arbitrary question, to compare general task difficulty with distractor objects, akin to Experiment 1. Different response patterns in each of the experiments may have been due to task difficulty, in that participants had to ignore one object in Experiment 1. There have been previous explorations of distractor effects, such as Ellis, Tucker, Symes and Vainio's (2007) finding of compatible grip responses in

distractor objects in a central object description task (Experiment 3), as opposed to objects differentiated by colour (Experiments 1, 2 and 4), in which distractor effects were not found. Indeed, participants would immediately be able to begin processing the one object in the current Experiments 2 and 3, whereas the agent's movement in Experiment 1 signalled the target object which participants were to categorise; thus the time course of responding may reflect changes in response mechanisms, for example the object moved closer to the opposite hand, the right hand potentially being more sensitive to such effects.

In terms of the interaction between wrist orientation and block, it is important to consider task difficulty. For example, it may be that the visual qualities of the vertical wrist orientation increase the difficulty of the task because more of the object area is occluded by the agent's grasp. This could be tested by the agent keeping her grip constant between conditions, so that the same proportion of each object can be seen, without constraining implicit grasping in the horizontal wrist orientation. However, the fastest responses were for the vertical wrist orientation in block 1. Evidently the horizontal wrist orientation is also more difficult after viewing a block of vertical wrist orientation stimuli, therefore differences in response times may not due to visual differences between the wrist orientations per se, but perhaps due to an entrained visual search, with which the change in order of presentation interfered.

The pattern of responding between blocks and wrist orientation may rather be due to more than one mechanical interaction. One interpretation may be comparison with Parsons' (1994) discovery that pictorial stimuli of realistic and comfortable wrist orientations facilitated participants' reaction times when compared to similar but unrealistic or uncomfortable stimuli. Therefore faster reaction times to the vertical wrist orientation rather than horizontal may be accounted for in this way. For block 2, reaction times are slower to vertical wrist orientations, which may be an indication that after viewing a block of stimuli in which the object would implicitly be available for grasping by either hand, as is the case with the horizontal wrist orientation, participant reaction times are slower in response to a constrained condition.

An alternative explanation may again be linked to task difficulty; block 2 is the more difficult due to the change of hand-mapping. Therefore responses may be facilitated by the horizontal wrist orientation when the task is more demanding, whereas for the less demanding task of block 1, mirror neurone or complementary action effects may be less prone to interfere with responses, possibly due to faster response times, if there is some hierarchy between mechanisms. Indeed, Ishida, Nakajima, Inase and Murata (2009) discovered differing responses to anatomical, spatial and bilateral stimuli in a dyadic interaction during single-cell recording. This may suggest specialised and discrete mimicry and interaction systems, akin to Clarke's (1997) contention of hierarchical mechanisms.

These are all highly speculative explanations for the results of Experiment 3, however, particularly given that the overall participant response by agent arm interaction reflects an SS effect, akin to Experiment 2. Although SS effects are often found in imitation experiments (van Schie, van Waterschoot, & Bekkering, 2008), van Schie, et al. (2008) found complementary action responses were elicited by careful use of methodology, suggesting that complementary actions may often be masked by SS responses, which may explain a lack of significant differences between wrist orientations in the current experiments. Also, consideration should be made of the

ecological framework of object transferral; the majority of people are right-handed, therefore it may be convenient to exchange objects in a right-handed fashion, regardless of one's own dominant hand. Indeed, left-handedness is not merely a mirror image of right-handedness (see, for example, Gazzaniga, Ivry, & Mangun, 2009). Differing effector responses reflecting differing roles is a claim also advanced by Vainio, Ellis, Tucker and Symes, (2006), suggesting that dominant hand responses may be specialised for fine-grained actions, akin to the local/global hemispheric difference, as reviewed by Gazzaniga, et al. (2009). Having to conform to a right-handed environment may, at least partially, explain this. The vertical wrist orientation may be preferred due to the kinematics of the arm; it is more comfortable in the shoulder, full wrist supination creating tension in the rotator cuff (Gray, 1977). The hand is similarly able to adjust its posture to an appropriate grip, the fingers making finer adjustments upon nearing the objects as discussed above (Jeannerod, 1984, as cited in Jacob & Jeannerod, 2003). This allows for dynamic interaction in a rapidly-changing environment, to the extent that finer adjustments in flight are not reported as conscious (Bridgeman, et al., 1979). Thus, it may be that the initial decision of response hand is not critical in terms of motor sequences because of the built-in accommodation to varying situations. The grip type and arm of response may be part of a sequence of motor decisions or they may be separately calculated on the fly. Palm-sized objects, such as those used here form a small proportion of the myriad object types and sizes we encounter. Such constrained effects are therefore, perhaps, likely to be small.

Further, it may be relatively uncommon for object transferral to occur from behind a desk, therefore a giver may ordinarily move their whole body towards the receiver, so that the anatomically congruent limbs are also spatially congruent, or more so than a scenario of reaching over a desk. Ellis and colleagues' (cf Ellis & Tucker, 2000; Ellis, et al., 2007; Symes, et al., 2005) research may reflect an ecological behavioural manifestation in that participants unconsciously respond to object micro-affordances. This may not be the case in social couplings, perhaps due to spatial changes during a person's approach.

The abstract nature of the Simon (1969) effect has been said to mimic more ecological scenarios, such as responding more quickly to real objects with the hand nearest that object (Ellis, 2007). In Experiment 3, most effects appear to manifest this SS behaviour, or the alternative interpretation of imitation, or indeed a mixture of both. Thus it may be that such mechanisms work in concert and are complementary, as suggested by Clark (1997), and careful consideration must be made to differentiate between imitation and SS effects in a behavioural paradigm.

Therefore, adding a micro-affordant factor other than wrist orientation to the current experiments may induce changes in response patterns, to disentangle SS effects from imitation. Objects in the current experiments were all palm-sized, affording a power grip. Objects which have two potential grasp types, such as a mug (i.e. the body of the mug and its handle), were used to elicit complementary actions in Newman-Norland et al.'s (2007) paradigm, participants responding with the right hand only. However, Ellis et al. (in press) found no micro-affordant effects in video stimuli in which the agent reached towards handled objects, i.e. participants were no faster at responding to the agent approaching the handle or the non-handle of the objects. This button-pressing task may elicit different responses to motor

entrainment response tools, as used by Ellis and Tucker (2000) (albeit that micro-affordances have been found using button-pressing also (Tucker & Ellis, 1998)). Also, it may be that the current experiments would change participant responding due to the agent holding the object from the first frame, rather than reaching towards the object as in Ellis et al. (in press). This could be combined with spatial changes, the agent's hand beginning at centre-back and reaching to the opposite side of the screen, in an attempt to discover whether faster responses are made to the agent's arm or the object, comparable with the SS responses in central object placement in the current Experiment 2. It may be possible to manipulate response times by asking participants to use differing temporal patterns of responding (e.g. responding immediately or otherwise (Vesper, van der Wel, Knoblich, & Sebanz, 2011), or it may be possible to elicit differing responses by placing more emphasis on the object. In the current experiments, most results reflected differences occasioned by aspects of the stimuli which were irrelevant to the explicit task. This is akin to research by Ellis and colleagues (Ellis, et al., in press; Ellis & Tucker, 2000; Ellis, et al., 2007; Symes, et al., 2005), all of which used an object categorisation task to measure implicit micro-affordances. However, despite the current experiments placing emphasis on the objects by use of a categorisation task, there were few effects of object micro-affordances constrained by the wrist contortions of the agent. A two task experiment in which participants categorise objects and are then required to measure the objects on a touch-screen with their fingers and thumb. The measurement aspect would in fact be a ruse to engage participants' attention to the location of the object and mimic grasping, albeit in a somewhat abstract manner.

It may also be that the inability to interact with the person through the computer screen has a different effect to that occasioned by the inability to interact with objects, eliciting different participant responses in the current experiments to those found by Ellis and colleagues (cf Symes, et al., 2005; Tucker & Ellis, 1998; Vainio, et al., 2007). Further investigation into more ecological scenarios may be warranted, similar to Griffiths and Tipper's (2009) staged social scenario, using face-to-face methodology (Experiments 2, 3 & 4). However, a social scenario does not record implicit responses, such as Koski et al.'s (2002) finding of greater activation for anatomically rather than spatially congruent tasks. Brain imaging techniques, such as EEG, may clarify this as well as the imitation and interaction mechanisms. Perry and Bentin (2009) found greater μ suppression for grasped object stimuli, whether videos or still images, rather than static or moving objects alone. This experiment was based upon Shmuelof and Zohary (2005), which found similar results using fMRI methodology. Therefore these techniques could be illuminating for the current experiments, given the potential vacillation between imitation, interaction and spatial processing and possible time-course manifestation.

Time course may be important in moving stimuli, such as Michaels' (1988) finding of faster responses to spatial congruence of stimuli with hand of response when the target object moved across the screen, participants responding more quickly to the end-position of the target. Reaction times in the current experiments indicated participants did not watch the entire video before making their response. The majority of participants viewed the first video in its entirety (being 1,000ms), as evidenced by the reaction times of the first practice trial (mean reaction time of all participants for trial 1 being 1143.10ms, compared with 704.78ms for the rest of the practice trials). It may be that once participants view one video, they are able to infer

that the events of subsequent videos remain largely identical, in line with the transfer of learning theory (Thorndike & Woodworth, 1901).

Comparable with Michaels (1988), Freyd (1983, as cited in Freyd, 1987) investigated implied movement, discovering a form of momentum in representation, finding that participants judged static images to have moved further on than in fact they had; that is, participants would view photograph pairs implying movement from the relative positions of the subject, for example a person jumping and appearing to have moved forward in the second image, and participants took longer to judge whether the images were identical when the photographs implied a forward motion, as opposed to when the photograph sequence was reversed, implying an ecologically implausible backward motion. Freyd (1983, as cited in Freyd, 1987) suggests this may be a judgment of continuing momentum, rather than accurately measuring the placement of the subject in the last image shown. Bach (personal communication, January 18, 2012) conducted a pilot study which found a similar effect with a series of still images of hands, moving a joystick either backward or forward to respond to an irrelevant explicit task.

In the current experiments, the agent fully extends her arm and the object stops moving before the end of each video. If participants are aware of this, they may not envisage her arm moving any further. In a scenario in which the agent placed the object centre back and moved the object into the arm's opposite hemisphere, participant responses may indicate whether participants respond to the moving object or limb, which latter may imply early processing of the agent's goal.

Changes in methodology can change SS responses, such as Michaels' (1988) DSS. Likewise, Vallesi, Mapelli, Schiff, Amodio and Umiltà (2005) propose two mechanisms for horizontal and vertical SS effects, again supporting the contention of competing spatial mechanisms. Therefore, another possible explanation for differing results in the current experiments may be spatial qualities of the objects and the agent's arms. In Experiment 1 the arms moved from side-back to centre-front, and in Experiment 2 centre-back to centre-front. The cross-body movement towards the table centre in Experiment 1 may evoke the unusual effects in right hand responses, arguably due to greater ecological validity of agent movement, i.e. movement comfort, as discussed above.

Longer response times appear to weaken SS response patterns. This may be interpreted as due either to the greater activation of a complementary mechanism or a DSS effect, as the object approaches the centre front (and this may be exaggerated by Freyd's momentum representation (1983, as cited in Freyd, 1987)). Again, these responses may be an admixture of both mechanisms, if Clark's (1997) argument for layered mechanisms is correct.

The raw data analysis may seem to support this contention because of the unusual right-handed response pattern. This changes to a clear SS manifestation on trimming, which largely removed longer reaction times. Thus, longer reaction times may be indicative of vacillation created by greater explicit task difficulty, the movement of the object across the screen, and/or implicit wrist orientation effects.

Results of Experiment 3 may therefore be in keeping with Experiment 1, in that SS response patterns are weakened or disappear, particularly when there is greater task

difficulty, such as in block 2 of Experiment 3, where there is also a speed/accuracy trade-off.

There is also evidence demonstrating a behavioural distinction between peripersonal and extrapersonal space (Bassolino, Serino, Ubaldi, & Lavadas, 2010; Serino, Annella, & Avenanti, 2009), suggesting responses only when objects are within reach. Costantini, Committeri and Sinigaglia (2011) and Griffiths and Tipper (2009) found similar effects, participants viewing objects within another agent's or their own reach, respectively. The camera was closer in Experiment 1 and 3 than in Experiment 2, thus possibly accounting for differing response patterns.

It seems, then, that differences in the agent's distance from the camera, or number of objects, or both, may have attributed to different results between Experiments 1, 2 and 3. Thus, further investigation by changing one of these factors may clarify response patterns. The rationale of the current experiments was to explore the spatial elements of the stimuli coupled with the micro-affordant (Ellis & Tucker, 2000) aspect of wrist orientation. Experiment 1 found faster participant responses to the actor's right arm, Experiment 2 found an SS effect. Comparison of Experiments 1 and 2 required clarification as to stimuli differences, in terms of the spatial presentation of the objects, camera proximity, number of objects, as well as a blocked wrist orientation factor.

The lack of distractor objects in Experiment 2 resulted in SS patterns of response, and in Experiment 3 the same was also largely true, thus differences occasioned by peripersonal space were not found. However, greater task difficulty, such as the wrist orientation and hand mapping changes between blocks may be related to changes in response patterns. Also, the lack of movement across the screen by the object in Experiment 2 may also explain the strong SS response pattern, akin to the horizontal and vertical SS mechanisms proposed by Vallesi, Mapelli, Schiff, Amodio and Umiltà (2005).

In ecological scenarios, it may often be the case that appropriate object transferral is facilitated by the receiver imitating the grasp type of the giver, rather than using a differing grasp. If it is the case that mirror neurones predict likely action goals (Csibra, 2007) strictly congruent mirror neurones would be useful in preparing a congruent grip to respond to the giver, albeit in the spatially opposite limb in an opposing wrist orientation, limb and wrist kinetics affording fine-tuning of grasps. This is supported by Ishida et al.'s (2009) discovery of neurones which preferentially respond to anatomical, spatial and bilateral stimuli, suggesting that differing response mechanisms, such as imitation and interaction, could be simultaneously activated until a final response is made; indeed Mukamel, Ekstrom, Kaplan, Iacoboni and Fried (2010) found neurones which oppositionally respond to mirror neurones, their explanation being that this was a mechanism to suppress imitative responding, initial fast responses perhaps being to analyse the goal of the moving object before calculating an appropriate response as suggested by Csibra (2007), reflected in the time course of differing behavioural responses.

To conclude, results between the current experiments were somewhat comparable. Right-handed responses for both the raw data and the vertical wrist orientation at block 2 of Experiment 3 echoed the results of Experiment 1. After trimming, results echoed those of Experiment 2, in an SS manifestation.

Therefore, viewing an agent in this particular scenario elicits an SS behavioural response, with task difficulty weakening these responses. Previous experiments have shown complementary action effects after motor entrainment (Knoblich & Sebanz, 2008), compared to the visually implicit entrainment here.

It is perhaps unsurprising that SS responses were greater overall in Experiment 3, given previous experiments, echoed in Experiment 2, yet some complementary action effects are found when there is a focus upon grip types (Newman-Norland, et al., 2007). One exception is Griffiths and Tipper (2009), in which participants were face-to-face rather than watching filmic stimuli on-screen.

Ellis and colleagues' (such as Symes, Ellis, & Tucker, 2005; Tucker & Ellis, 1998; Vainio, et al., 2007) research demonstrates implicit object responses, despite participants being unable to act upon those objects. SS responses could be described as similar, however clarification is needed as to whether more naturalistic paradigms may change responses in social couplings, or time course reflects a processing hierarchy, as proposed by Csibra (2007).

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